



Effect of metabolizable energy and crude protein levels on performance, fertility, hatchability and egg quality of Rajasri breeder birds

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ABSTRACT

This study investigated the impact of different levels of dietary energy and crude protein on productive performance, egg quality, and reproductive parameters in Rajasri breeder birds during a 12-week period between 25 to 36 weeks of age. A total of 648 birds were divided into nine dietary treatments, each with eight replicates, following a 3 × 3 factorial arrangement of three dietary metabolizable energy levels (2400, 2500, and 2600 kcal ME/kg) and three crude protein levels (14, 15, and 16%). The results of the study indicated that metabolizable energy had a significant effect on feed intake, egg weight, body weight, yolk colour, and shell thickness. However, there was no significant effect of energy on egg production and feed efficiency. An increase in egg weight was observed as crude protein levels increased in the diet, but there was no significant difference in albumin quality, yolk index, and shape index. Yolk colour was higher in the 2600 kcal ME/kg fed group. Furthermore, the study found that there was no significant effect of ME and CP levels on the percentage of shell, but shell thickness decreased as energy increased. There was also no significant effect on density and shell breaking strength, fertility, hatchability on total eggs set (TES), and hatchability on fertile eggs set (FES). Based on the findings, concluded that the Rajasri breeder birds require a diet containing 2400 kcal ME/kg and 14% CP for optimal productive and reproductive performance.

Keywords: Energy, Fertility, Hatchability, Performance, Protein, Rajasri breeders

The main purpose of the poultry industry is to achieve optimum production with minimal inputs. In poultry farming, feeding cost alone involves 65–75% of total production cost. Because of increasing feed ingredients cost, it has become important to balance the nutrient intake to optimise the production cost without affecting performance of birds. Rajasri is a variety developed by PV Narsimha Rao Telangana Veterinary University, Hyderabad and is an excellent dual purpose variety. This variety has been distributed to rural people to cater the needs and to alleviate malnutrition in rural areas. This breed is known for its strong disease resistance ability and outstanding performance. However, nutrient requirements for this breed were formulated based on the nutrient recommendations for other (Commercial) layer breeds/strains. Therefore, standardization of nutrient requirements of this breed has become important. Optimization of nutrient requirements, i.e. energy and protein of this developed variety is mandatory to improve its productive, reproductive fitness and helps farmers to reduce cost of feeding. As metabolizable energy (ME) and crude protein (CP) are the two main and expensive nutrients, they should

be considered first. Van emous *et al.* (2021) diluted the diet density (ME & CP) by 10% from standard (2700 Kcal ME and 14% CP) and did not find any effect on performance of broiler breeders during 03 – 40 weeks of age. Cerrate *et al.* (2018) fed broiler breeders with the three protein levels, i.e. 15.38, 16.57, 14.79% CP from 25–36 weeks and 14.73, 15.77, 13.98% CP from 37–60 weeks of age and concluded that, 14.79% and 13.98% CP adequate during 25–36 weeks and 37–60 weeks, respectively. Van emous *et al.* (2015) evaluated low protein diets in broiler breeders and obtained adequate performance, fertility and hatchability during 22–45 weeks of age.

Many studies were carried out to standardize ME and CP requirements in commercial layers and breeders, but the published data related to Rajasri breed is very limited. Therefore, the objective of this study was to determine the effects of ME and CP on performance, reproduction and egg quality.

MATERIALS AND METHODS

Birds and management: An experiment was conducted using 648 Rajasri hens from 25 weeks of age to 36 weeks of age. The hens were individually leg banded, kept in individual layer cages and randomly assigned to one of the nine diets (eight replicates with 9 hens per replicate). Birds were fed on experimental diets for a period of six weeks for adaptation. The birds had *ad lib.* access to feed and water

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throughout the experiment. The hens were housed under standard conditions of temperature (26–28°C), relative humidity (40–60%), and ventilation. A lighting program of 16 h of light and 8 h of dark with a light intensity of 50 lux at bird level was used for the entire experimental period. The experimental diets were fed for a period of 12 weeks. All hens were weighed at the beginning of the trial at 25 weeks of age.

Experimental diets and treatments: The experiment was a 3 × 3 factorial completely randomized design with 3 dietary energy levels with 3 dietary protein levels. The nine experimental diets were as follows: T1-2400 kcal ME / kg diet +14% CP; T2-2400 kcal ME / kg diet +15% CP; T3-2400 kcal ME / kg diet +16 % CP; T4-2500 kcal ME / kg diet +14% CP; T5-2500 kcal ME / kg diet +15% CP; T6-2500 kcal ME / kg diet +16 % CP; T7-2600 kcal ME / kg diet + 14% CP; T8-2600 kcal ME / kg diet + 15% CP; T9-2600 kcal ME / kg diet +16% CP (Tables 1 and 2).

Performance traits: Feed intake (FI) was determined weekly by subtracting the ending feed weight of each replicate from the beginning feed weight. Egg production and egg weight were recorded daily. Mortality was determined daily so that the feed consumption could be adjusted accordingly. Eight hens from each replicate were weighed individually at the beginning and at the end of the experiment. Based on these data, hen-day egg production, egg weight (EW), FI, feed efficiency per dozen eggs (FE) were calculated.

Egg quality: Seventy two eggs (one egg from each replicate) were randomly collected to assess egg quality parameters. The eggs were weighed and cracked. The egg density was measured by dipping the egg in water using egg density kit (KIT 128, product code WX-002–00014, LCGC, Poland) fitted to precision balance (AS220/X, Radwag LCGC, Poland). The Haugh unit (HU) was

measured using Haugh unit meter (S 8400, AMES, Melrose, MA, USA) by fixing the weight of egg and measuring the height of thick albumen. Eggshell thickness (without the eggshell membrane) was measured at 3 sites (blunt, middle, and sharp) of the egg, and the mean of the 3 parts was calculated.

Reproductive parameters: Eggs from all replicates were collected for three consecutive days at the end of each period. Small eggs (below 40 g), large eggs (above 60 g), hair line cracked eggs, broken eggs and misshapen eggs were discarded. The remaining eggs were considered as hatching eggs. Starting at 25 weeks of age 24 eggs from each group from last 3 to 4 d of every week were collected and set, after a 2 d storage period, in an incubator at a commercial hatchery. Eggs were candled on d 18 of incubation and clear eggs and dead in shell were opened to determine infertility and the timing of mortality by visual observation. On d 18, eggs were transferred to pedigree boxes and placed in hatchery. At d 21 of incubation, unhatched eggs were calculated. Fertility was determined using the formula.

Fertility % = 100 (number of fertile eggs/number of total eggs set)

Hatchability of set and fertile eggs was calculated as the percentage of chicks hatched of set and fertile eggs, respectively.

Hatchability % on total eggs set = 100 (no. of chicks hatched / no. of total eggs set)

Hatchability % on fertile eggs set = 100 (no. of chicks hatched / no.of fertile eggs set)

Statistical analysis: The mean of each replicate was used as the experimental unit in the statistical analysis. Data were subjected to 3 × 3 factorial analysis to test the main effects of ME and CP concentrations and their interaction (Snedecor and Cochran 1980). Mean values

Table 1. Ingredient composition of the dietary treatments

Ingredient (%)	Diets								
	2400 kcal / kg diet			2500 kcal / kg diet			2600 kcal / kg diet		
	14% CP	15% CP	16% CP	14% CP	15% CP	16% CP	14% CP	15% CP	16% CP
Maize (%)	49.60	48.40	47.00	54.10	53.50	53.01	60.16	59.80	59.40
Soyabean meal (%)	7.800	11.00	14.40	10.70	11.50	15.00	11.60	14.00	16.00
De-oiled rice bran (%)	22.29	20.61	19.78	18.86	15.42	12.83	12.00	8.782	5.397
Sunflower cake (%)	11.00	10.70	9.600	7.000	10.30	10.00	6.900	8.100	10.00
Stone grit (%)	6.840	6.900	6.900	6.900	6.900	6.800	6.900	6.900	6.800
Di-calcium phosphate (%)	1.550	1.500	1.458	1.550	1.500	1.500	1.550	1.550	1.550
Salt (%)	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
DL-Methionine (%)	0.000	0.000	0.010	0.003	0.000	0.015	0.010	0.015	0.020
Lysine HCl (%)	0.092	0.06	0.025	0.058	0.055	0.017	0.047	0.023	0.003
Antibiotic (%)	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Trace Mineral Mixture (%)	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Vitamin AB ₂ D ₃ K (%)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Vitamin B-Complex (%)	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Choline chloride 50% (%)	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
Toxin binder (%)	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2. Nutrient composition of dietary treatments

Nutrients	Diets								
	2400 kcal / kg diet			2500 kcal / kg diet			2600 kcal / kg diet		
	14% CP	15% CP	16% CP	14% CP	15% CP	16% CP	14% CP	15% CP	16% CP
Metabolizable Energy (Kcal/kg)	2403	2402	2405	2502	2501	2500	2602	2603	2602
Crude Protein (%)	14.03	15.04	16.00	14.02	15.01	16.00	14.00	15.01	16.02
Ether Extract (%)	2.170	2.130	2.100	2.330	2.290	2.260	2.500	2.470	2.440
Crude Fibre (%)	7.800	7.680	7.550	6.660	7.050	6.700	5.710	5.680	5.720
Calcium (%)	3.010	3.020	3.020	3.030	3.020	2.990	3.030	3.030	3.000
Available Phosphorous (%)	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Lysine (%)	0.644	0.691	0.736	0.644	0.690	0.736	0.644	0.690	0.736
Methionine (%)	0.284	0.304	0.323	0.282	0.300	0.324	0.283	0.302	0.323

* Trace mineral provided per kg diet: Manganese 120 mg, Zinc 80 mg, Iron 25 mg, Copper 10 mg, Iodine 1 mg and Selenium 0.1 mg.

** Vitamin premix provided per kg diet: Vitamin A 200000 IU, Vitamin B2 25 mg, Vitamin D3 3000IU, Vitamin K 2 mg, Riboflavin 25 mg, Vitamin B1 1 mg, Vitamin B6 2 mg, Vitamin B12 40 mg and Niacin 15 mg.

were compared using Duncan's (1955) multiple range test at $P < 0.05$.

RESULTS AND DISCUSSION

Egg production (EP): In the present experiment, egg production ($P > 0.05$) was not influenced by effect of dietary treatments nor main effects i.e. three different levels of ME and CP during 25 – 36 weeks of age (Table 3). Results obtained are in agreement with the findings of Zhang *et al.* (2013), Rama Rao *et al.* (2014) and Mikulski *et al.* (2020) in laying hens at different phases of the production cycle. Traineau *et al.* (2015) found similar results in layer hens by reducing dietary ME from 2600 to 2300 kcal / kg diet without affecting the hen day egg production during 26 – 39 weeks of age. Mikulski *et al.* (2020), who fed reduced ME to brown hens did not find any effect on hen day production during 37 – 47 weeks. Above two studies corroborate the findings of present study. Author attributed this to ability of laying hens to adjust their feed intake to dietary energy and unaffected feed intake (Mikulski *et al.* 2020). Hens might have adjusted their feed intake in response to energy only in the peak egg production of laying cycle, perhaps adjusting to the nutrient balance of the feed (Depersio *et al.* 2015). The results of the present study showed that, different CP levels (14, 15 & 16%) did not affect percent hen day egg production in Rajasri breeder hens during 25 – 36 weeks of age. Similarly in other studies, different levels of CP did not affect hen day egg production (Hocking *et al.* 2002, Rama Rao *et al.* 2011). In a study by Cerrate *et al.* (2018), reduced protein from 16.5% to 14% in broiler breeder hens supplemented with amino acids in a ratio to CP did not affect hen day egg production. In the present study, amino acids are supplied in optimum ratio to CP percent and results are in accordance with the findings of Rama Rao *et al.* (2011) and Cerrate *et al.* (2018). However, in the present study, White Leghorn birds were not used, so we speculate that the Rajasri breeder hens could tolerate lower nutrients and produce eggs at sufficient levels. Based on the present study, the metabolizable energy 2400 kcal/kg

with 14% CP diet was sufficient to maintain optimum egg production in Rajasri breeder hens during 25 – 36 weeks of age.

Feed intake (FI): In our study, decrease in feed consumption (Table 3) observed as the ME content of the diet increased from 2400 to 2500 and 2500 to 2600 kcal ME / kg diet. In 2600 kcal ME / kg fed group, feed consumption was reduced by 5.3% compared to 2400 and 2500 kcal ME / kg fed groups. Similar results are also obtained by Rama Rao *et al.* (2014) and Kang *et al.* (2018), where authors found that for every 39 kcal ME / kg increase, 1% of feed intake reduces (Wu *et al.* 2005). Laying hens regulate their feed consumption as a function of their energy requirement, and therefore, birds with similar production and genetic strain, tend to regulate their energy intake (Ribeiro *et al.* 2014). There was no significant difference ($P > 0.05$) observed by feeding different levels of CP (14, 15 and 16%) on overall mean feed consumption during the present study. Our results are in accordance with the findings of Torki *et al.* (2015) who reported that reduction of CP from 16% to 13% in *Lohmann LSL lite* hens did not affect the feed consumption; the reason could be that diets containing marginal amino acid levels, such as lysine, total sulphur amino acids and arginine levels did not result in an increased feed intake. In the present study, amino acids (Lysine and DL - methionine) were supplied at constant ratio to CP at each level according to NRC (1994) recommendation, which might have satisfied the birds appetite for amino acids. In contrast to our findings, Rozenboim *et al.* (2016) found an increase in feed consumption when hens offered an increasing concentrations of CP in the diet.

Body weight: In the present study, body weights were significantly ($P < 0.05$) affected by the feeding different levels of energy during 25 – 36 weeks of age (Table 3). The findings of present study are consistent with Li *et al.* (2013) and Depersio *et al.* (2015) who observed similar effect of ME on body weight in laying hens at different ages. In a similar study by Perez Bonilia *et al.* (2012) with *Hy-line* brown layers (24–59 weeks of age), observed an increase

Table 3. Performance of Rajasri breeder birds fed with different metabolizable energy (ME) and crude protein (CP) levels during 25 – 36 weeks of age

Metabolizable energy (ME) (kcal/kg)	Crude protein (CP) (%)	Egg production	Feed intake	Egg weight	Egg mass	Feed efficiency / Dozen eggs	Initial Body Weight	Final Body Weight
2400	14	65.08	104.9	47.41 ^c	30.90	1.974	1401	1605
	15	66.83	105.0	48.16 ^{bc}	32.22	1.928	1373	1594
	16	65.21	101.8	47.77 ^{bc}	30.93	1.896	1407	1619
2500	14	65.32	105.8	48.75 ^{bc}	31.80	1.988	1383	1637
	15	67.03	102.6	49.70 ^a	33.34	1.858	1349	1623
	16	65.65	101.2	48.66 ^{abc}	31.83	1.876	1416	1659
2600	14	62.45	99.20	48.45 ^{abc}	30.24	2.016	1417	1726
	15	67.11	96.50	48.79 ^{bc}	32.72	1.746	1376	1638
	16	64.97	96.16	50.97 ^a	33.30	1.812	1416	1709
n		8	8	8	8	8	8	8
P value		0.932	0.826	0.001	0.560	0.443	0.979	0.778
SEM		1.937	1.625	0.408	1.028	0.059	31.37	33.08
<i>ME</i>								
2400		65.71	103.9 ^a	47.78 ^b	31.35	1.933	1394	1606 ^b
2500		66.00	103.2 ^a	49.04 ^a	32.32	1.907	1383	1640 ^{ab}
2600		64.84	97.3 ^b	49.41 ^a	32.09	1.858	1403	1691 ^a
P value		0.751	0.001	0.001	0.486	0.289	0.729	0.008
SEM		1.118	0.938	0.235	0.594	0.034	18.11	19.10
<i>CP</i>								
	14	64.28	103.3 ^a	48.20 ^b	30.98	1.993 ^b	1400	1656
	15	66.99	101.4 ^{ab}	48.88 ^a	32.76	1.844 ^a	1366	1618
	16	65.28	99.77 ^{ab}	49.14 ^a	32.02	1.861 ^a	1413	1662
	P value	0.230	0.032	0.018	0.110	0.005	0.169	0.214
	SEM	1.118	0.938	0.235	0.594	0.034	18.11	19.10

Means in columns not sharing a common superscript differ significantly (P<0.05).

in body weight when fed with ME ranging from 2650 – 2950 kcal / kg, each with 100 kcal incremental levels and attributed increase in body weight to feeding high ME containing diets. In the present study, we speculate that, since the Rajasri breeder hens were elite birds with native inheritance, the excess energy more than production needs was may be diverted for increase in body weight gain rather improvement in egg mass production (Perez-Bonilia *et al.* 2012). In contrast to present study, Rama Rao *et al.* (2014) did not find effect of energy on body weight of laying hens. CP levels did not affect the body weights of Rajasri breeder hens in the present study during 25–36 weeks of age. Similar study was conducted by Lesuisse *et al.* (2017) in broiler breeder hens with reduction of 25% CP i.e. 16 % to 11.55% during 21–40 weeks of age and did not find any effect of low CP on body weight.

Feed efficiency per dozen eggs: In the present study, different levels of metabolizable energy and crude protein did not affect the feed efficiency per dozen eggs of Rajasri breeder hens from 25–36 weeks of age (Table 3). This is in agreement with the previous reports, changes in dietary ME levels did not significantly affect feed efficiency. Reducing energy from 2880 to 2790 kcal ME / kg (Murugesan and Persia 2013) or from 2872 to 2667 kcal ME / kg (Silva *et al.* 2012) or from 2902 to 2303 kcal ME / kg (Trineau

et al. 2015) failed to affect feed efficiency of laying hens at different ages. Similarly, Depersio *et al.* (2015) observed a significant effect of ME on feed efficiency of laying hens. Crude protein levels significantly (P<0.05) affected overall mean feed efficiency per dozen eggs of Rajasri breeder hens. Feed efficiency was improved as the crude protein level increased from 14–16% of the diet. Similar study was conducted by Shim *et al.* (2013) in laying hens by feeding 2 and 4% low crude protein diets than control (19.05%) and observed a decrease in feed efficiency and attributed the poor efficiency to availability of low level of amino acids in low CP diets. On the other hand, Torki *et al.* (2015) and Ding *et al.* (2016) did not observe any effect of low protein diets on feed efficiency. The no response to decreased protein levels in the above studies could be due to supplementation / balancing of amino acids in low crude protein diets (Ding *et al.* 2016).

Egg weight: Interaction of ME and CP significantly (P<0.05) affected mean egg weight of Rajasri breeder birds during 25–36 weeks of age (Table 3). In the present study, at constant CP level, the egg weight increased with the increasing ME from 2400 to 2600 kcal / kg diet. At constant ME, i.e. 2400 and 2500 kcal/kg diet level, increasing protein from 14 to 16% did not improve egg weight or remains same, whereas at 2600 kcal/kg diet, increasing

Table 4. Reproductive performance and egg quality parameters of Rajasri breeder birds fed with different metabolizable energy (ME) and crude protein (CP) levels during 25 – 36 weeks of age

ME (kcal/kg)	CP (%)	Fertility (%)	Hatchability (%) (TES)	Hatchability (%) (TES)	HU	Albumin index	Yolk index	Yolk colour	Shell percentage (%)	Shell thickness (mm)
2400	14	93.33	88.89	95.56	85.89	0.077	0.465	6.634	9.914	0.359
	15	85.00	81.67	96.67	85.19	0.077	0.474	6.822	10.06	0.345
	16	89.45	86.11	96.67	84.68	0.069	0.457	6.444	9.978	0.355
2500	14	91.11	85.56	94.45	84.49	0.075	0.458	6.871	9.931	0.347
	15	88.89	84.45	95.56	87.65	0.074	0.458	6.822	9.724	0.347
	16	86.11	85.00	98.89	82.8	0.073	0.471	6.994	9.890	0.353
2600	14	91.11	86.67	95.56	84.38	0.073	0.472	7.200	9.602	0.343
	15	86.67	83.34	96.67	84.6	0.074	0.477	7.267	9.633	0.344
	16	92.22	85.00	92.78	84.91	0.078	0.476	7.321	9.839	0.350
n		8	8	8	8	8	8	8	8	8
P value		0.576	0.947	0.419	0.398	0.271	0.180	0.125	0.656	0.207
SEM		3.053	3.689	2.100	1.458	0.002	0.006	0.108	0.147	0.004
<i>ME</i>										
2400		89.26	85.56	96.30	85.25	0.074	0.465	6.633 ^c	9.986	0.353 ^a
2500		88.70	85.00	96.30	84.98	0.074	0.462	6.896 ^b	9.848	0.349 ^{ab}
2600		90.00	85.00	95.00	84.63	0.075	0.475	7.263 ^a	9.691	0.346 ^c
P value		0.873	0.978	0.684	0.870	0.800	0.033	0.019	0.053	0.044
SEM		1.763	2.130	1.212	0.842	0.001	0.004	0.062	0.085	0.002
<i>CP</i>										
	14	91.85	87.04	95.19	84.92	0.075	0.465	6.902	9.816	0.350 ^{ab}
	15	86.85	83.15	96.30	85.82	0.075	0.470	6.970	9.808	0.345 ^c
	16	89.26	85.37	96.11	84.13	0.073	0.468	6.634	9.902	0.353 ^a
P value		0.140	0.436	0.786	0.371	0.454	0.637	0.444	0.683	0.043
SEM		1.763	2.130	1.212	0.842	0.001	0.004	0.062	0.085	0.002

Means in columns not sharing a common superscript differ significantly (P<0.05).

protein levels from 14 to 16% significantly improved egg weight. Egg weight in the present study was significantly increased with increasing ME from 2400 to 2600 kcal/kg diet. Results are in consistent with the reports of Sunder *et al.* (2007) who observed increase in egg weight by feeding increased nutrient density in feed in *cobb-500* broiler breeders, respectively. On the contrary, Zhang *et al.* (2013) and Rama Rao *et al.* (2014) reported no effect of ME on egg weight in their studies. Egg weight was affected by level of CP (P<0.05), findings of Shim *et al.* (2013) and Lesuisse *et al.* (2017) are in consistent with present study results, whereby reduced egg weight reported by feeding low protein (25% reduced) diet in broiler breeder hens and (4% reduced) White Leghorn layers, respectively. This response was probably due to the low feed intakes, which resulted in intake of low protein and amino acids below the NRC (1994) recommended levels (Shim *et al.* 2013).

Reproductive parameters: In the current study, fertility (P>0.05) was unaffected by level of ME, CP and their interaction (Table 4). Comparable effect was reported by Van emous *et al.* (2015) when *Ross-308* broiler breeder birds fed on diets containing 2600, 2800 and 3000 kcal ME/kg diet during 22–45 weeks of age. In contrast, Sunder *et al.* (2007) observed a negative effect of low energy on fertility of broiler breeder hens by reducing energy from 2600 to

2340 kcal ME/kg diet. No effect of CP was observed on fertility in the present study. Hocking *et al.* (2002) did not observe effect of reduced dietary protein from 18.5 to 15% in *Ross-308* broiler breeder hens and the unaffected fertility could be due to *ad lib.* feeding rather than restricted feeding in broiler breeder hens during 19 – 64 weeks of age. Similarly, Rao *et al.* (2009) did not find any effect of reduced protein diet from 15% to 10% in *Langshan* breeder hens during 44–48 weeks of age.

Hatchability percentage on total eggs set (TES) and fertile eggs set (FES) was not in the present study. Similarly, Prakash *et al.* (2014) observed no effect on hatchability by reducing ME from 2730 to 2470 kcal / kg diet in Dahlem red layers during 31–50 weeks of age and reported nutrient density could be decreased in diet up to 5% of their normal diet. In accordance to our results, Hocking *et al.* (2002) also reported decreasing CP levels from 18% to 15% did not affect hatchability percentage of *Ross-308* broiler breeder birds during 19 – 64 weeks of age. Similarly, Lesuisse *et al.* (2017) and Cerreate *et al.* (2018) reported that low protein intake of 11.80% to 13% is required for optimum reproductive functions for the broiler breeders. This explains the unaffected hatchability % of Rajasri breeder birds, the supplied 14% CP might have met the requirements of birds (Walsh and Brake 1997).

Egg quality parameters: Haugh unit and albumen index were unaffected by ME and CP levels in the present study (Table 4). These results are in agreement with the findings of Zhang *et al.* (2013) and Depersio *et al.* (2015). Ding *et al.* (2016) conducted a similar trial in layer hens by reducing energy and protein levels in the diets from 2750 to 2650 kcal ME/kg and from 15.5 to 14.5%, respectively and did not find any effect on Haugh unit and albumen index during 33–41 weeks of age. Contrary to the results obtained in the present study, Torki *et al.* (2015) and Lesuisse *et al.* (2017) observed a decrease in Haugh unit of laying hens by feeding reduced protein diets.

Yolk quality was not influenced by either the interaction or dietary levels of ME and CP. Similar to the current findings, Perez-Bonilia *et al.* (2012), Zhang *et al.* (2013) and Kang *et al.* (2018) did not find any effect of ME levels on yolk quality in laying hens. Mean yolk colour was higher in high ME fed group and colour intensity increased as the energy (Maize) concentration increased in diets. It could be due to amount of pigments (Xanthophyll) in the maize, as xanthophyll was the key component that controls the yolk colour (Ding *et al.* 2016). CP levels did not influence the yolk quality in the present study and results are in agreement with the findings of Mousavi *et al.* (2013) and Depersio *et al.* (2015). Percentage of shell was unaffected ($P>0.05$), whereas shell thickness ($P<0.05$) was affected either by interaction of ME and CP or dietary levels of ME and CP. Gunawardana *et al.* (2008) did not find any effect of reducing 300 kcal ME in *Hy-line* laying hens on percentage of shell. However, Perez-Bonilia *et al.* (2012) reported a decrease in percentage of shell as the ME concentration increased in *Hy-line* brown laying hens from 24–59 weeks of age. Ding *et al.* (2016) reported a significant decrease in shell thickness as energy increased from 2650 to 2750 kcal ME/kg diet. Mousavi *et al.* (2013) reported a decrease in shell thickness as protein increased in the diet and concluded that shell thickness decreases as egg weight increases.

Based on the results it can be concluded that 2400 kcal ME/kg diet and 14% crude protein are sufficient for optimum egg production, egg weight, feed efficiency and reproductive parameters during 25–36 weeks of age.

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